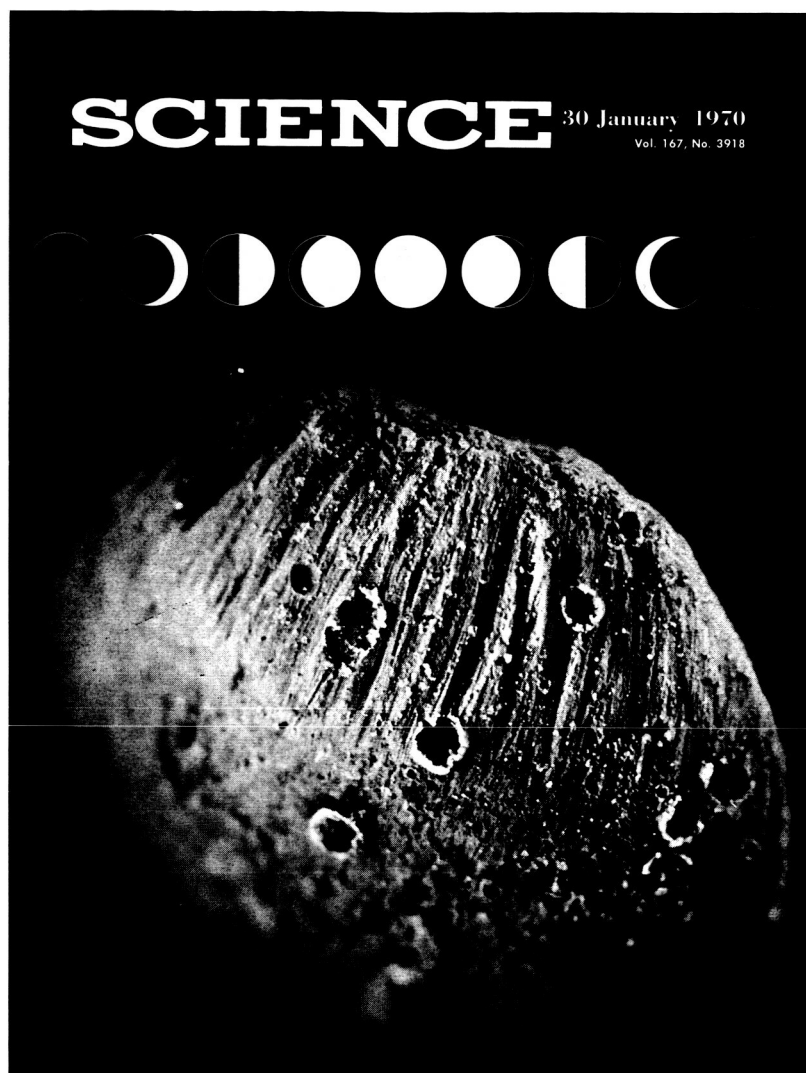


# SCIENCE

## Apollo 11 Lunar Science Conference



### Magnetic Properties of Lunar Dust and Rock Samples

Charles E. Helsley

(NASA-CR-141129) MAGNETIC PROPERTIES OF  
LUNAR DUST AND ROCK SAMPLES (Texas  
Univ.) 4 p

N75-70120

Unclas  
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## Magnetic Properties of Lunar Dust and Rock Samples

*Abstract. Determinations on 20- to 80-milligram portions of the rock samples and the -150 mesh fraction of the lunar dust show pronounced Curie points between 680° and 780°C. Remanent intensities of five rock fragments vary from  $8.4 \times 10^{-5}$  to  $0.30 \times 10^{-5}$  emu/gram. Upon demagnetization, two of the samples had only viscous magnetization and two other samples had stable magnetizations with remanent coercivities in excess of 50 oersteds. Partial thermal demagnetization suggests that these apparently stable moments may have been acquired in a magnetic field in excess of 1500 gammas.*

Current theories regarding the origin of the earth's magnetic field require the presence of a conducting fluid core (1, 2). Consequently, it is of considerable interest to know whether the moon ever had an appreciable magnetic field. If it had one in the past, the implication would be that the interior was at one time a conducting fluid or that the

moon was within the earth's magnetic field at the time the rock cooled. Studies of the magnetic properties of five Apollo 11 lunar rock samples, as well as the dust, show that some of the samples have a stable magnetic moment that could have been acquired as a result of cooling in the presence of a magnetic field. The samples studied are (i)

a fragment of rock sample 10022, a vesicular basalt with spherical vesicles; (ii) a fragment of rock sample 10069, a fine-grained basalt with irregular vesicles; (iii) a fine-grained gabbro from dust sample 10085,16 fragment 2; (iv) a vesicular basalt fragment from dust sample 10085,16, which is similar to sample 10022 fragment 4; and (v) a fine-grained basalt fragment from dust sample 10085,16, which is similar to sample 10069; and (vi) the -150 mesh fraction of dust sample 10084.

Thermomagnetic analyses were made on the -150 mesh portion of each sample by sealing 10- to 100-mg portions in evacuated quartz glass tubes which were placed in a magnetic force balance in a high gradient field of about 2 kilo-oersteds, and heated at a rate of 1° to 2°C per second to a temperature of up to 800°C. The results of these analyses are shown in Fig. 1. The most prominent Curie point in the dust samples is between 750° and 770°C, suggesting the presence of native iron with very low nickel content. The dust sample also yields a prominent Curie point in the vicinity of 180°C after it has been heated to 800°C. This transition is also present in the initial heating curve but is only evidenced by a very slight change in slope near

200°C. When the sample is cycled below 500°C, the heating and cooling curves are very similar, and the 200°C transition remains very obscure. When cycled to 650°C, this transition becomes more prominent and when cycled to 720°C, the 200°C transition becomes quite pronounced. When the dust is heated beyond 600°C, the heating and cooling curves are quite different, suggesting that a chemical change has occurred within the sample.

Small portions (approximately 75 mg) of each of the larger rock samples (10022 and 10069) were also subjected to thermomagnetic analysis. The results of these experiments are also shown in Fig. 1 and are in general very similar to those for the dust samples. These samples were also cooled to -196°C in order to check for any ilmenite Curie points. For sample 10069 a Curie point near -170°C seems indicated, but sample 10022 shows no evidence of a Curie point above -196°C. High-temperature Curie points for sample 10069 occur at 520°C and in the range 680° to 752°C. These are not reproducible during cooling; instead they are replaced by one at 690° to 700°C and another at 115°C. In sample 10022, the high-temperature Curie points are at 485°C and at > 680°C and upon cooling at 465°C.

All of the above observations are not characteristic of normal basalts found on the earth. Instead they have many similarities to those reported by Stacey *et al.* (3) from chondritic meteorites. This suggests that the major magnetic constituents in these samples are iron with a low nickel content, perhaps a pyrrhotite or troilite(?), and an abundant ilmenite phase with very little, if any, Fe<sup>3+</sup>.

Initial measurements of the natural remanent magnetization (NRM) of the three rock fragments from the dust sample 10085,16 and the two rocks 10022 and 10069 yielded specific intensities ranging from  $8.41 \times 10^{-5}$  emu/g to  $0.297 \times 10^{-5}$  emu/g. Two of the small samples had previously been exposed to an external field of about 60 oersteds during petrologic examination in a scanning electron microscope. Consequently, their NRM might be expected to be anomalous. The NRM moments of the three samples that had not been exposed to large external fields are  $2.46 \times 10^{-5}$ ,  $1.92 \times 10^{-5}$  and  $0.297 \times 10^{-5}$  emu/g.

All samples were subjected to alternating field demagnetization with peak

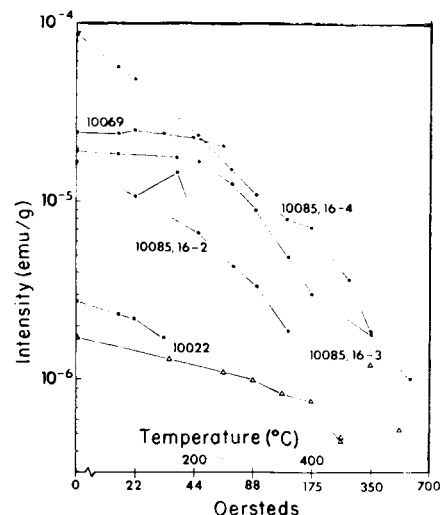


Fig. 2. Progressive alternating field (circles) and thermal demagnetization curves (triangles) for rock samples studied. Note use of log scale.

fields varying from 11 to 570 oersteds, and the results are shown in Fig. 2. Samples 10069 and fragment 3 from dust sample 10085,16 have a stable NRM and have remanent coercivities in excess of 44 oersteds. Both these samples appear to be of the same rock type. Fragments 2 and 4 from the dust sample (the ones that had been in the scanning electron microscope) show only an IRM and no stable NRM. One is a fine-grained gabbro and the other a fragment of vesicular basalt similar to 10022. Upon alternating field demagnetization, they show an almost linear decrease on a log-log scale. Sample 10022 is more stable than fragments 2 and 4, yet it does not show the stability evidenced by fragment 3 and sample 10069.

After being demagnetized in an alternating field of 33 oersteds, sample 10022 was further demagnetized by progressive thermal demagnetization in a vacuum at intervals of 50°C. The results of this demagnetization are shown in a log-linear plot at the bottom of Fig. 2. In a second heating after the 250°C and 350°C demagnetization steps, the sample was allowed to cool in an applied field of 1000 gammas for the first 100°C and then to cool the rest of the way in the absence of any applied field (4). The ratio of the intensity lost in the temperature interval to that gained during cooling in the 1000-gamma field is 1.88 and 1.57 for the intervals 150° to 250°C and 250° to 350°C, respectively. Progressive thermal demagnetization showed an increasing rate of decrease in remaining

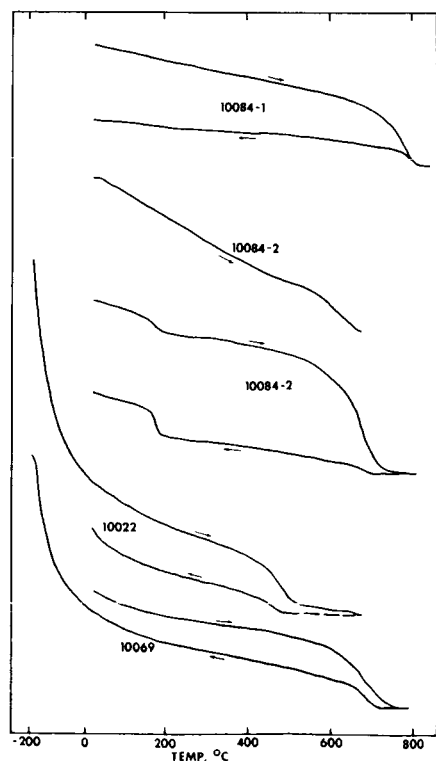


Fig. 1. Selected thermomagnetic analysis curves for lunar dust and rock samples. Vertical scale is arbitrary. Arrows indicate direction of temperature change.

moment up to 450°C, as is characteristic of samples with distributed thermal blocking temperatures. Above 450°C, no reliable demagnetization results could be obtained. The cause of this instability is not known, but it may be the result of exceeding the pronounced Curie point at 485°C (Fig. 1). The moment due to the phase with the higher Curie point may be unstable, or it may be that it is completely overridden by the moment acquired during cooling through the 465°C transition in a small residual field (10 to 20 gammas).

After alternating field demagnetization, fragment 3 of the dust sample was heated in vacuum to 450°C and allowed to cool in a field of 500 gammas. No additional detectable moment was acquired during this process. This sample was then heated in vacuum to 750°C and allowed to cool in an applied field of 1000 gammas. Again no detectable moment was acquired, indicating that it acquired its NRM in a field in excess of 20,000 gammas or that it was acquired by some means other than cooling through the Curie point. Alternatively, an irreversible chemical change may have taken place in the sample so that remanence can no longer be acquired in the same way the initial NRM was acquired.

Thus the evidence from fragment 3 of the dust sample allows no estimate of the possible range of values for the moon's field in the past. The partial thermal demagnetization of sample 10022 suggests that the sample may

have acquired its initial NRM in a field of 1500 to 2000 gammas. However, the marked instability at higher temperatures leaves this conclusion somewhat in doubt; it is subject to verification by apparently more stable samples such as sample 10069.

Thermomagnetic analysis of the Apollo 11 dust and rock samples studied indicates that the major magnetic minerals are ilmenite, native iron, and possibly pyrrhotite. Of these, the native iron and the pyrrhotite (troilite?) are the dominant carriers of the natural remanence in these rocks. The natural remanences are low in all these samples in comparison with similar rocks from the earth. The stability of the NRM is low in three of the samples studied but is high in the other two. If the NRM of these samples is interpreted as being a TRM acquired by passage through the Curie point in the presence of a magnetic field, a field in excess of 1500 gammas is suggested.

CHARLES E. HELSLEY  
University of Texas at Dallas,  
(formerly Southwest Center  
for Advanced Studies),  
P.O. Box 30365, Dallas 75230

#### References and Notes

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4 January 1970